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Line Chilling of Beef 1: The Prediction of Temperatures

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ABSTRACT

The main objective of the work was to investigate the feasibility of replacing the present batch chilling process applied to beef carcasses, by a line or continuous process. In a commercial situation, this would result in greater efficiency and better process control while maintaining the production of top quality meat. In the course of the experimental work, 11 different chilling regimes were applied to 79 carcasses. A chilling regime consists of a sequence of 'zones' of varying air temperature, air speed and duration. Meat temperatures were quite successfully predicted from computer programs which were based on the nomographs compiled by Bailey and Cox (1976) and published by the Meat Industry Development and Advisory Service (UK) (1978).

INTRODUCTION

The importance of chilling in the beef slaughter industry is well recognised at this stage. The principal reason for chilling is to minimise bacterial growth and thus prolong shelf life.

Meat has been chilled by mechanical refrigeration for about 100 years. However, Cutting (1972) states that 'existing knowledge is not being fully applied because the meat industry still operates largely on traditional lines, so that its refrigeration procedures are often inadequately planned, monitored and controlled'. In speaking about advances in chilling beef by mechanical refrigeration, Bailey and Cox (1976) state that 'the majority of these developments have been concerned with the mechanical plant, with little attention to the problems arising on the chill-

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room side of the evaporator'. They go on to say that 'a careful search of the literature will reveal almost every conceivable combination of air temperature, velocity and relative humidity as recommendations for cooling carcasses. Such a state of affairs exists because the majority of the data quoted have been obtained in commercial abattoirs where inability to vary operating conditions, poor instrumentation, and lack of attention to carcass variables have often led to erroneous conclusions'.

Another problem in the industry has been the lack of communication between refrigeration design engineers and meat scientists. Cutting (1971) states that 'refrigeration engineers do not possess the information needed about meat for design of plant to extract heat at a specified rate'. Winstanley (1987) says that 'too often, refrigeration equipment is designed to the requirements of the evaporator without due consideration to the product. Often this arises because operators specify their requirements only in terms of overall rate of heat transfer, without considering the thermal properties of the meat'.

The above quotations are just a small sample from numerous publications, which indicate the degree of confusion which exists among processors, research workers and designers of refrigeration plant.

Overall objective

The overall objective of this work is to investigate the feasibility of cooling beef carcasses post slaughter by using a continuous chilling system instead of the more conventional batch chilling system. Inevitably, economic factors play the biggest part in determining the feasibility of any process. The increasing cost of energy, especially that which comes from non-renewable sources, is forcing industry to use energy more efficiently. According to Briley (1980): 'During the last three decades, most process industries have been expanding energy in lieu of capital. It was always easy to justify the lowest price. Almost invariably, the low priced refrigeration system had much higher energy requirements than the system with the higher cost.' In summary, the purpose of this work is to find ways of making the carcass cooling process more efficient and more controllable, while ensuring that meat of high quality is produced in so doing.

Ideal cooling rate

In the beef industry, the ideal rate of cooling will be a compromise between such factors as:

(a) adherence to EC regulations
(b) speed of throughput
(c) avoidance of cold toughening
(d) minimising weight loss

The Council of the European Communities' (1964) Council Directive on health problems affecting intra-Community trade in fresh meat, states in Chapter IX of Annex I that 'fresh meat intended for intra-Community trade must be chilled immediately after the post-mortem inspection and kept at a constant temperature not more than + 7°C for carcasses and cuts and + 3°C for offal'. This is interpreted to mean that all parts of a carcass for export to other EC countries, must be chilled down to 7°C before removal from the factory.

Speed of throughput is an important factor because the longer it takes to chill the meat to the required specifications, the more working capital is tied up in meat and the more chilled space is required to store this meat. Collett and Gigiel (1986) carried out a study of the energy usage and weight loss in five commercial beef chillers. They found that 'if the EEC requirement of 7°C in the deep muscle is to be met in beef, then chilling periods of 48 h are necessary with existing chillers'. Wootton (1986) also quotes data which indicate that achieving 7°C in the deep round within 24 h is possible only with very small sides (those < 88 kg). The deep round is defined as the thermal centre of a side of beef, i.e. the position which cools most slowly. Ideally, factories would like to operate on a 24-h cycle, in which meat would be shipped out on the day after slaughter, i.e. after 18–20 h of chilling. James and Bailey (1989) state that it is 'virtually impossible' to chill beef to 7°C within 18 h with the current single-stage systems. 'The only possible solution is to design specialised systems utilising one or more pre-chill stages, but the air temperatures required are so low that it is extremely difficult to avoid some degree of surface freezing.'

Cold toughening (cold shortening) is caused by post-mortem biochemical effects which are still not fully understood. Bendall (1972) suggested that in order to avoid cold toughening, meat should not be cooled below 10°C within 10 h of slaughter i.e. before the onset of *rigor mortis*. This has become quite a well-known rule of thumb, in the absence of more detailed knowledge on how to avoid toughening being made available to processors.

Shrinkage (weight loss) is defined conventionally as the per cent loss of mass based on the initial hot unwashed mass of the side after slaughter and dressing. Economically, it is a very important factor from the factory owner's point of view. According to Collett and Gigiel (1986): 'as profits in slaughtering are low, often < 1% of turnover, a small reduction in weight loss can make a substantial improvement in financial return'. In a study which compared the relative capital costs, running costs and the cost of weight loss between different types of chilling system, Bowater (1986) found that the greater capital and running costs associated with a rapid chilling system can be more than compensated for by savings in evaporative weight loss. Rapid chilling reduces weight loss by cooling the surface of the side quickly and thus reducing the potential for evaporation.

Mechanically cooled moving air systems are still considered to be more economical than the novel methods such as cryogenic chilling using liquid N_2. Briley (1980) states that 'mechanical refrigeration is the least expensive way to chill or freeze a food product. It uses less energy than any other system'.

Batch chilling

All over the world, beef carcasses are cooled in batch chills. The carcasses move into the chill at the rate of about one per minute. An average chill has six to eight lines, each containing 15 to 20 suspended carcasses, but there is a lot of variation. Normally rails are spaced about 1·0–1·2 m apart. Carcass density along the rail is usually in the range 0·75–0·9 m/carcass. Most commonly, a row of fans down one or both sides of the chill blows air over the evaporator coils, where it is chilled by means of heat transfer between the air and the refrigerant in the coils. From the coils the cold air is blown into the chill in order to cool the sides of beef.

Batch chilling systems have many disadavantages in terms of efficiency of energy and labour use and in terms of meat quality. These may be summarised as follows:

(a) seasonal variation in carcass supply
(b) evaporator design problems
(c) irregular cooling pattern
(d) heat gain through open doors
(e) inefficient use of labour
(f) sizing of fans

Seasonal variation in carcass supply is a problem in countries like Ireland where most of the total beef production is slaughtered in a short time span. According to CBF (1990), 47% of cattle slaughtered in Ireland in 1989 were slaughtered in the months October to December. The peak/trough slaughter ratio in 1989 on a weekly basis was 7·5:1. In practice, batch chills are run at the same rate regardless of the load. Thus in a partially full batch chill, the energy consumption per carcass is greater than in a full chill. Having a batch chill which is partially full may also lead to process control problems; for example, greater carcass spacing may lead to higher air speeds and consequently higher cooling rates.

As mentioned above, beef chilling systems in the past have been designed with very little regard for the thermal characteristics of the product. A lot of existing batch chills have problems which should have been eliminated at the design stage, but were retained because the alternative would have been too expensive. There are many chills with evaporator coils that are too small in area for efficient running of the refrigeration plant. The evaporator is the component of a mechanical refrigeration plant which transfers heat from the chilled medium (usually air in the case of food chills) to the low pressure, low temperature refrigerant inside the coils. The degree of heat transfer achieved depends upon the temperature difference between the air and the refrigerant, the overall heat transfer coefficient of the coil (including convective effects) and the area of the coil. Because the evaporator is an expensive component, the tendency in the meat industry has been to choose a relatively small evaporator coil. However, this requires a more powerful compressor to achieve the necessary lower refrigerant temperature in the evaporator. The effect is to lower the coefficient of performance of the plant. This is the low capital cost, high running cost option. Choosing a larger evaporator with a lower power compressor costs more initially, but is more energy-efficient in the long term. There are two additional advantages associated with this configuration. Because there is a smaller temperature difference between the refrigerant and the air, less water from the air will freeze onto the coils. This keeps the relative humidity high which reduces the potential for evaporative weight loss. Also, the evaporator coils need to be defrosted less frequently, which further enhances the efficiency of the system. The other design fault which is frequently found in chills is evaporator fans which run constantly. Collett and Gigiel (1986) report that out of five beef chilling systems which they studied, four 'were controlled such that all evaporator fans ran continuously except during defrosts, resulting in significant base demands and much higher energy requirements'. The other plant had a base demand of zero in winter 'because the plant was controlled such that evaporator fans cut out with the compressor when the room set temperature was achieved'.

Air flow patterns in chills are extremely difficult to predict. It is probable that carcasses on the lines nearest the fans will be subjected to higher air speeds and lower air temperatures than those hanging further away from the fans. In a study designed to find the causes of variability in beef temperatures after 24 h of chilling, Wootton (1986) found that 'the most interesting result of the experiment is the great importance of the location of a beef side in the chill'. No two chills have the same characteristics unless they are the same in every detail. It is possible that even a slight raising or lowering of the evaporator fans may have a dramatic effect on the air-flow pattern throughout the chill. Chill dimensions, fan power, distance between rails and packing density on rails may cause unexpected effects, e.g. gaps between sides may provide a short cut for the air stream. Generally, experienced operators will know where the 'cold spots' are in a particular chill. Wootton concludes that 'if the effect of the location in a chill is known, it follows that it should be possible to arrange the distribution of sides such that those judged to need a faster rate of cooling can receive it'. As quality considerations become more and more important in the modern market-place, this low level of control over the cooling rate is becoming unacceptable.

The average chill as described above would take two to three hours to fill. The doors usually stand open during this time because the carcasses arrive too frequently to allow them to close. Heat gain through the open doors is a significant load on the refrigeration system. It occurs during the peak product load when carcass temperatures are highest. Carcasses reach their highest temperature between one and two hours after slaughter, due to post-mortem metabolic heating.

Carcasses must be removed manually, even in modern plants, from the slaughter hall to the chill. The adoption of a line chilling system should eliminate this inefficient use of labour, by transferring carcasses automatically from the dressing line to the chilling line.

An additional disadvantage of batch chills is the requirement for very high powered fans. The third fan law states that the power consumed by a fan varies as the cube of the volumetric flow rate from the fan. For example, to double the fan discharge (and thus the velocity) requires an eight-fold increase in power consumption. In addition, fan energy must be removed by the refrigeration plant. This supports the case for reducing the number of lines of carcasses which must be cooled by a row of fans.

Line chilling

The idea of line or continuous chilling is in keeping with current trends in the food industry generally. On the whole, processors have found that when throughput is sufficiently high, the higher capital cost of continuous plant relative to batch equipment, is easily offset by the advantages of better control and lower running costs in terms of energy and labour.

In the line, the beef sides would pass slowly down a long serpentine tunnel, while being subjected to a particular chilling regime. A chilling regime consists of a sequence of 'zones', wherein air speed and temperature are very precisely controlled. The number of zones and the length of time spent in each would be variable depending upon the type of carcasses being chilled and their intended use. The carcasses would move into a holding chill at the end of the cooling period, where temperature equalisation and maintenance would take place.

The idea of continuous chilling of beef carcasses has been broached by research workers in the past. Wernberg (1972), in a review of quick chilling procedures in Scandinavian countries, describes how 'tunnels with serpentine conveyors through two or more partitioned temperature zones established by the overhead evaporators, are also used with advantage in some of the large Scandinavian beef killing plants'. Ortner (1989) describes a process known as 'shock chilling' which is used in Germany to reduce weight loss from pork and beef carcasses. In the case of beef, the carcasses pass through a tunnel for three hours with the air temperature in the range of −4 to 0°C. The carcasses then pass into a holding chill where cooling progresses as in a normal batch chill.

Experimental work

The experiments were carried out in a small experimental chill at The National Food Centre. This paper will be concerned with the initial stage of the experimental work; developing a method of choosing suitable chilling regimes and predicting the results of applying them. The chilling experiments and their results will be described in a later paper (Drumm *et al.*, Line chilling of beef 2, this issue).

MATERIALS AND METHODS

Chilling regimes were chosen using the nomographs compiled by Bailey and Cox (1976) and published by the Meat Industry Development and Advisory Service (1978), as a guideline. There are four nomographs. Each one represents the cooling characteristics of a different location in a beef side; the deep round (deep leg), the surface round, the centre *longissimus dorsi* and the surface *longissimus dorsi.*

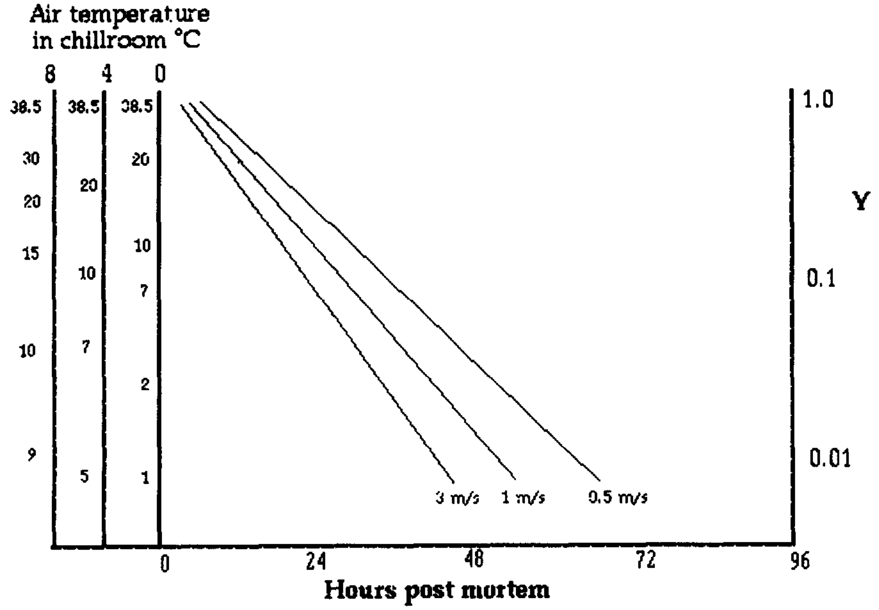

Fig. 1. Typical form of nomograph published by MIDAS (1978). It plots dimensionless temperature Y against time for various air speeds. The right hand axes represent different air temperatures. Plots will vary with carcass size.

Figure 1 illustrates the nomograph format for the deep round location. Y is a dimensionless temperature given by the following formula:

$$Y = (t_m - t_a)/(38{\cdot}5 - t_a)$$

where t_m = meat temperature (°C), t_a = chiller air temperature (°C) and 38·5 = meat temperature at slaughter (°C).

The graphs may be used to determine the cooling time to a particular meat temperature, given the side weight, the air speed and the air temperature. It must be noted that air was blown vertically downwards over the sides in the experiments used to develop these graphs. Alternatively, the temperature of the meat after chilling for a certain length of time in particular conditions may be ascertained.

The deep round is the thermal centre of a side of beef, i.e. the slowest cooling location. The deep round temperature must be considered when a certain maximum temperature is to be reached within a specific time limit, e.g. to adhere to EC regulations. The temperature of the surface of the *longissimus dorsi* is used to judge the risk of cold shortening (associated with toughening of meat). According to Bailey and Cox

(1976): 'To avoid cold shortening completely the surface of the *longissimus dorsi* must remain above 10°C' for 10 h. This is based on the findings of Bendall (1972), who advised that 'lamb or beef carcasses should not be chilled below 10°C until at least 10 hours after slaughter. Only under these conditions can optimal tenderness be ensured'.

Computer programs were written in GW-BASIC on an IBM-compatible PC to make the nomographs easy to use. The following algorithm forms the basis of the programs:

1. By interpolating between the lines for the 100 kg sides and the 140 kg sides, lines for 120 kg sides were inserted on the nomographs. 120 kg was the anticipated average side weight of animals to be used in the experimental work.
2. The equation of these lines was determined in the format $y = mx + c$, where x = time post mortem y = vertical 'height' from the horizontal axis on the graphs (as published by MIDAS, 1978), m = gradient of the line and c = y-axis intercept.
3. Input the number of zones, followed by the air speed, temperature and number of hours relating to each zone.
4. Use hours and speed of first zone to calculate the height.
5. Use the height to calculate Y which is on a log scale.
6. Use Y and air temperature to calculate and print out the meat temperature at the end of the first zone.
7. Calculate a new Y using meat temperature and air temperature of second zone.
8. Use the new Y to calculate a new height.
9. Use this new height and speed of the second zone to calculate the equivalent number of hours required in second zone conditions to achieve the temperature after the first zone.
10. Add this equivalent number of hours to the second zone hours and use the total as the second zone hours in the loop which starts again at point 4 above.
11. Repeat for all zones.
    Note: This method of predicting meat temperatures is only intended for use as a guideline. The algorithm doesn't take account of the change in temperature gradient from one zone to the next. Also, in compiling the graphs, air was blown vertically downwards over the sides, rather than horizontally on to the round.

Appendix A contains the prediction program for the deep round location. Table 1 is a summary of the chilling regimes which were chosen to chill beef carcasses for the first 24 h postslaughter.

TABLE 1
Summary of Chilling Regimes

Regime	*Air speed* $(m\,s^{-1})$	*Temperature, hours* (°C, h)
A	0·5	7, 24
B	1·7	7, 24
C	0·1	7, 24
D	3·7	7, 24
E	1	−2, 5; 7, 19
F	1	−5, 5; 7, 19
H	1	−6, 4; 7, 20
I	1	−6, 6; 7, 18
J	1	7, 10; 0, 14
K	1	−6, 6; 7, 4; 0, 14

A, B, C and D were intended to simulate conventional-style chilling, i.e. the air temperature remains constant for the whole of the chilling period. The air temperature was set to 7°C on the basis that the surface of the *longissimus dorsi* would reach 10·4°C after 10 h in these conditions (assumed air speed 0·5 m s^{-1}). Four different air speeds were tried at this temperature.

E, F, H and I each have a 'cold conditioning' zone at the beginning. The carcasses are then conventionally chilled for the remainder of the chilling process. It is well known that reducing the surface temperature as quickly as possible after slaughter, reduces the potential for evaporative weight loss.

Regime J has two zones. The first is similar to the conventional-style chilling described above. The second starts at 10 h *post mortem*. The air temperature is reduced severely in order to try to lower the deep round temperature as quickly as possible.

K and L each have three zones. The first is a cold conditioning zone similar to regimes E, F, H and I. The second zone uses air at 7°C for 4 h. The third is a low-temperature zone commencing at 10 h post slaughter, similar to regime J. The objective of regimes K and L is to find a compromise between the following attributes:

1. minimal shrinkage
2. acceptable toughness
3. fast temperature reduction

TABLE 2
Predicted and Actual Deep Round Temperatures for Each Regime

Regime	*Temperature (°C)*					
	I	*II*	*III*	*IV*	*V*	*VI*
A	28·5	15·8	27·08	14·13	23·39	11·71
B	25·9	12·7	25·61	12·55	23·66	11·91
C	>28·5	>15·8	28·81	16·82	27·22	16·13
D	<24·7	<11·9	25·78	12·24	23·34	11·71
E	27·5	14·3	27·20	14·10	24·09	12·58
F	27·4	14·3	27·14	13·82	24·76	12·62
H	28·0	14·5	27·39	13·81	25·15	12·74
I	26·7	14·0	27·34	13·91	25·02	12·74
J	27·8	9·9	28·03	11·95	26·90	10·40
K	26·7	9·5	27·42	11·41	25·52	9·40
L	26·7	8·2	26·73	10·52	25·02	8·29
SED[a]			0·597	0·512	0·559	0·407
p			<0·001	<0·001	<0·001	<0·001

[a] SED = standard error of differences of means.
p = probability
Predicted values: I: Deep round temperature after 10 h.
II: Deep round temperature after 24 h.
Measured values: III: Inner deep round temperature after 10 h.
IV: Inner deep round temperature after 24 h.
V: Outer deep round temperature after 10 h.
VI: Outer deep round temperature after 24 h.

RESULTS AND DISCUSSION

Deep round (DR) temperatures

Table 2 contains the actual (mean values in both the inner and outer chambers) and predicted deep round (DR) temperatures for each regime, 10 h and 24 h after slaughter. Predicted temperatures for regimes A and C were calculated using 0·5 m s^{-1} as the air speed. An air speed of 2 m s^{-1} was used for regime B and an air speed of 3 m s^{-1} was used for regime D. The table also contains the results of the analysis of variance on the actual temperature data. These indicate that there are very significant differences ($p < 0{\cdot}001$) between regimes with respect to DR temperatures measured 10 h and 24 h after slaughter.

Analysis of variance carried out on DR temperatures with respect to inner and outer chambers showed that there was a very significant difference ($p < 0{\cdot}001$) 10 h and 24 h after slaughter between DR temperatures measured in the inner and outer chambers. It is evident from the table that temperatures in the inner chamber are substantially higher than those in the outer chamber. This was caused by the lower air speeds from the fan in the inner chamber (Drumm *et al.*, Line chilling of beef 2, this issue).

On the whole, there is very good agreement between actual and predicted deep round temperatures. After 10 h, inner chamber temperatures agree very closely. Actual temperatures range from 1·4°C lower (A) to > 1·1°C higher (D) than predicted temperatures. Results are not as good in the outer chamber. The range is from 0·9°C lower (J) to 5·1°C lower (A). After 24 h in the inner chamber, the range is 2·3°C higher (L) to 1·7°C lower (A). In the case of the outer chamber, the range is 0·5°C higher (J) to 1·8°C lower (H).

Deep *longissimus dorsi* (DL) temperatures

Table 3 is equivalent to Table 2 except that it refers to the deep *longissimus dorsi* location. It was compiled in the same way using the predictor program for the DL location. Again, analysis of variance showed that the different chilling regimes produced very significantly different ($p < 0{\cdot}001$) DL temperatures at 10 h and at 24 h post slaughter. However, in this case there is no significant difference between chambers with respect to DL temperatures.

After 10 h, actual temperatures are 2·0°C higher (K inner and I outer) and 2·4°C lower (A outer) than predicted temperatures. After 24 h, actual temperatures are 1·4°C higher (L outer) and 0·3°C lower (B inner) than predicted temperatures.

CONCLUSIONS

It should be possible to use the prediction programs based on the work of Bailey and Cox (1976) and published by MIDAS (1978), in the commercial situation as an aid to designing chilling processes. The programs were originally written simply as a guide to choosing chilling regimes. Temperatures were predicted quite successfully, despite approximations which were made, e.g. interpolation for 120 kg sides. If this idea was expanded to cater for a range of side weights and possibly a

TABLE 3
Predicted and Actual Deep *longissmus dorsi* Temperatures for Each Regime

Regime	*Temperature (°C)*					
	I	*II*	*III*	*IV*	*V*	*VI*
A	12·4	7·4	11·47	7·64	10·02	27·64
B	10·8	7·2	9·76	6·94	10·89	7·40
C	> 12·4	> 7·4	12·06	8·33	12·68	8·35
D	< 8·3	7·0	8·85	6·93	9·31	7·37
E	9·1	7·1	10·21	7·48	10·21	7·49
F	8·5	7·1	9·95	7·46	10·07	7·58
H	9·2	7·1	10·37	6·98	10·16	6·89
I	7·2	7·0	9·70	7·42	9·24	7·47
J	10·8	0·4	11·05	1·54	11·68	1·61
K	7·2	0·3	9·21	1·46	9·12	1·28
L	7·2	− 1·6	8·15	− 0·48	8·55	− 0·15
SED[a]			0·664	0·396	0·718	0·440
p			< 0·001	< 0·001	< 0·001	< 0·001

[a] SED = standard error of differences of means.
p = probability
I: Predicted temperature of deep *longissimus dorsi* temperature after 10 h.
II: Predicted temperature of deep *longissimus dorsi* temperature after 24 h.
III: Measure temperature of inner deep *longissimus dorsi* temperature after 10 h.
IV: Measured temperature of inner deep *longissimus dorsi* temperature after 24 h.
V: Measured temperature of outer deep *longissimus dorsi* temperature after 10 h.
VI: Measured temperature of outer deep *longissimus dorsi* temperature after 24 h.

greater range of air speeds, then it could be used to help choose suitable regimes for a line chilling system.

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APPENDIX A

Deep round temperature prediction program

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5 PRINT "TEMPERATURE IN DEEP ROUND"
10 INPUT "NUMBER OF ZONES";N%
15 DIM V(50), TA(50), H(50), L(50), Y(50), TM(50), HX(50), YX(50),
LX(50)
20 FOR I = 1 TO N%
25  PRINT "ZONE"I
30  INPUT "VELOCITY= ",V(I)
40  INPUT "TEMPERATURE = ",TA(I)
50  INPUT "NUMBER OF HOURS = ",H(I)
60 NEXT I
65  IF N% = 1 GOTO 230
70  FOR I = 1 TO N%-1
80  H(I) = H(I) + HX(I-1)
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90 IF V(I) = .5 THEN L(I) = -2.51*H(I) + 192
100 IF V(I) = 1 THEN L(I) = -2.89*H(I) + 194.5
110 IF V(I) = 2 THEN L(I) = -3.37*H(I) + 195.5
120 IF V(I) = 3 THEN L(I) = -3.63*H(I) + 195.5
125 IF V(I)< >.5 AND V(I)< >1 AND V(I)< >2 AND V(I)< >3
THEN 310
130 Y(I) = 10^(L(I)/91)*.01
140 TM(I) = Y(I)*(38.5-TA(I)) + TA(I)
145   PRINT “TEMPERATURE AFTER ZONE “I” = “TM(I)”DEG.C”
150 YX(I) = (TM(I)-TA(I + 1))/(38.5-TA(I + 1))
155 LX(I) = (LOG(YX(I)/.01)/LOG(10))*91
160   IF V(I + 1) = .5 THEN HX(I) = (LX(I)-192)/(-2.51)
170   IF V(I + 1) = 1 THEN HX(I) = (LX(I)-194.5)/(-2.89)
180   IF V(I + 1) = 2 THEN HX(I) = (LX(I)-195.5)/(-3.37)
190   IF V(I + 1) = 3 THEN HX(I) = (LX(I)-195.5)/(-3.63)
210 NEXT I
220 H(N%) = H(N%) + HX(N%-1)
230   IF V(N%) = .5 THEN L(N%) = -2.51*H(N%) + 192
240   IF V(N%) = 1 THEN L(N%) = -2.89*H(N%) + 194
250   IF V(N%) = 2 THEN L(N%) = -3.37*H(N%) + 195.5
260   IF V(N%) = 3 THEN L(N%) = -3.63*H(N%) + 195.5
265   IF V(N%)< >.5 AND V(N%)< >1 AND V(N%)< >2 AND
V(N%)< >3 THEN 310
270 Y(N%) = 10^(L(N%)/91)*.01
280 TM(N%) = Y(N%)*(38.5-TA(N%)) + TA(N%)
290 PRINT “THE FINAL TEMPERATURE IN THE DEEP ROUND
IS” TM(N%) “DEG. C”
300 END
310 PRINT “ERROR: AIR VELOCITY INCORRECT”
```